

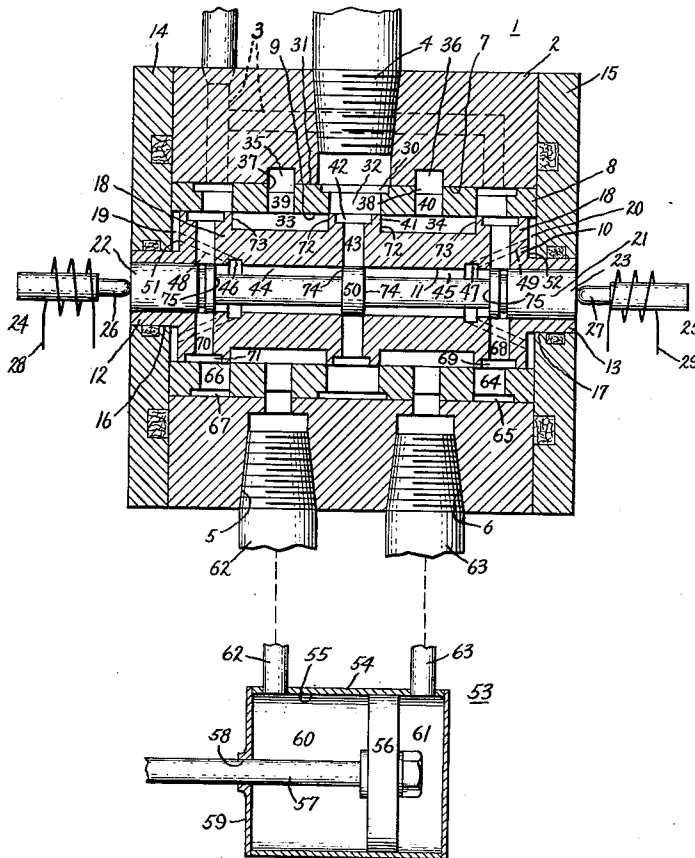
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E. R. WALTHERS

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TWO-STAGE HYDRAULIC CONTROL VALVE

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Inventor:
Earle R. Walthers,
by *Claude F. Walther*
His Attorney.

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TWO-STAGE HYDRAULIC CONTROL VALVE

Earle R. Walthers, Schenectady, N. Y., assignor
to General Electric Company, a corporation of
New York

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This invention relates to two-stage proportional hydraulic control valves and has for its object the provision of a simple, reliable proportional hydraulic control valve in which the effect of reaction forces is minimized to reduce the actuating force required to operate the valve while maintaining stable operating conditions therein.

In general, my invention consists of a two-stage proportional hydraulic control valve in which the operation of a relatively large main valve thereof is controlled in proportional response to the operation of a relatively small concentrically positioned pilot valve.

For a complete understanding of my invention, reference should be had to the following specification and the accompanying drawing which is a cross-sectional view of a hydraulic control valve illustrative of my invention.

Referring to the drawing, I have shown therein a proportional hydraulic control valve 1 illustrative of my invention and comprising a housing 2 having a dump passageway 3 and inlet passageway 4, a pair of working passageways 5 and 6, and a hollow cylindrical interior surface 7. Each of the passageways 4-6 is spaced in the housing 2, as shown in the drawing. Passageways 3 and 4 provide communication between the exterior and interior of the housing 2, and passageways 5 and 6 extend from the exterior of the housing 2 a predetermined distance in the direction of the interior thereof.

A cylindrically shaped valve sleeve 8 having a cylindrical bore or interior 9 is assembled in fixed position within the interior surface 7 of the housing 2. A cylindrically shaped main valve 10 having a hollow cylindrical interior surface 11 and opposite ends 12, 13 of reduced diameter is slidably positioned in the interior 9 of the valve sleeve 8. The housing 2 is provided with a pair of opposite closed ends 14, 15 having a pair of aligned apertures 16 and 17 respectively located in the opposite ends 14, 15 as shown in Fig. 1, to accommodate respectively the projecting ends 12, 13 of the main valve 10. A main body portion 18 of the main valve 10 is made of shorter length than the length of the housing 2 to form a pair of pressure chambers 19 and 20, one at each end of the main valve 10 between adjacent surfaces of the housing ends 14 and 15, the main valve 10, and the valve sleeve 8.

Within the cylindrically shaped interior surface 11 of the main valve 10, I provide a pilot valve 21 having a relatively small diameter as compared with the diameter of the main valve 10. The pilot valve 21 is slidably positioned in

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the interior surface 11 of the main valve 10 and has opposite ends 22, 23 exposed to the exterior of the housing 2.

The pilot valve 21 is operated by any suitable device. For example, I prefer to use a pair of proportional solenoids 24, 25 having respective armatures 26, 27, and respective operating coils 28 and 29 and positioned one at either end of the pilot valve 21 to provide engagement of the armature 26 of the solenoid 24 with the end 22 of the pilot valve 21 and engagement of the armature 27 of the solenoid 25 with the end 23 of the pilot valve 21. An example of proportional solenoids suitable for operation of the pilot valve 21 is shown in U. S. Patent 2,435,817 of Boynton et al., assigned to the same assignee as this present application. The pilot valve 21 is arranged for slidable movement on the interior surface 11 of the main valve 10 in accordance with the relative energization of the coils 28, 29 of the respective solenoids 24, 25.

To provide for the passage of fluid under pressure from the inlet passageway 4 to a selected one of the working passageways 5 and 6, dependent upon the slidable position of the main valve 10 in the valve sleeve 8, an annular groove 30 communicating with the passageway 4 is formed in the outer periphery 31 of the valve sleeve 8. A plurality of apertures 32 communicating with the groove 30 are formed in the valve sleeve 8. A pair of spaced annular grooves 33 and 34 are formed in the outer periphery of the valve sleeve 10 on opposite sides of the aperture 32 of the valve sleeve 8. A pair of spaced annular grooves 35 and 36 communicating respectively with the working passageways 5 and 6 are formed in the interior surface 7 of the housing 2. A pair of spaced annular grooves 37 and 38 communicating respectively with the annular grooves 35 and 36 are formed in the exterior periphery of the valve sleeve 8. A plurality of spaced apertures 39 communicating with the annular groove 37 of the valve sleeve 8 and annular groove 33 of the main valve 10 are formed in the valve sleeve 8. A plurality of spaced apertures 40 communicating with the annular groove 38 of the valve sleeve 8 and the annular groove 34 of the main valve 10 are formed in the valve sleeve 8.

It will be noted that the formation of the annular grooves 33 and 34 in the main valve 10 provides a land 41 aligned with the apertures 32 of the valve sleeve 8 to interrupt communication between the passageway 4 and the grooves 33 and 34 when the main valve 10 is in the "off" position, as shown in Fig. 1. Thus, for the "off"

position of the main valve 10, fluid under pressure is prevented from passing to either of the working passageways 5 and 6. However, when the main valve 10 is slidably moved to the right, communication is established through the groove 33, associated apertures 39 and associated grooves 37 and 35, to the working passageway 5. Thus, fluid under pressure is passed from the passageway 4 to the passageway 5 when the main valve 10 is moved to the right. Conversely, when the main valve 10 is moved to the left from the "off" position, fluid under pressure is passed from the passageway 4 through the annular groove 34 of the main valve 10 and associated apertures 40 and grooves 38 and 36 aligned with the annular groove 34 to the working passageway 6. Moreover, the amount of displacement to the left or right of the main valve 10 from the "off" position is determinative of the area of apertures 32 utilized to pass fluid to the selected passageway 5 or 6 and therefore determines the flow of fluid through the two-stage control valve 1.

To operate the main valve 10 in response to the operation of pilot valve 21 by solenoids 24 and 25 and to control the movement of the main valve 10 proportionally to the movement of the pilot valve 21, an annular groove 42 is formed in the land 41. A plurality of apertures 43 aligned with the annular groove 42 are formed in the main valve 10 to provide communication between the annular groove 42 and the interior of the main valve 10. A pair of spaced annular grooves 44 and 45 are formed in the outer periphery of the pilot valve 21. A pair of spaced annular grooves 46 and 47 are formed in the interior surface 11 of the main valve 10. A plurality of spaced apertures 48 associated with the annular groove 46 are provided in the main valve 10 to provide communication between the annular groove 44 of the pilot valve 21 and the pressure chamber 19, and a plurality of spaced apertures 49 associated with the annular groove 47 are formed in the main valve 10 to provide communication between annular groove 45 of the pilot valve 21 and the pressure chamber 20. It will be noted that the formation of the annular grooves 44 and 45 in the pilot valve 21 provides a land 50 aligned with the spaced apertures 43 of the main valve 10 when the pilot valve 21 is in the "off" position, as shown in Fig. 1.

Considering the structure of the main valve 10 and the pilot valve 21 as immediately defined above, it will be noted that for the "off" position of the pilot valve 21, as shown in Fig. 1, fluid under pressure in the passageway 4 is prevented from passing to either of the pressure chambers 19 or 20 by the land 50. However, when the pilot valve 21 is moved to the right in response to operation of the solenoid 24, the land 50 is also moved to the right, thereby uncovering the apertures 43 in the main valve 10 to permit the passage of fluid under pressure from the passageway 4 through the apertures 43, annular groove 44, annular groove 46, and apertures 48 to the pressure chamber 19. Fluid under pressure thereby admitted to the pressure chamber 19 acts upon an annular surface 51 of the main valve 10 to force the main valve to the right and thereby allow fluid under pressure in the passageway 4 to be directed to the working passageway 5.

However, the distance through which the main valve 10 is moved to the right is dependent upon the distance through which the pilot valve 21 is moved to the right. That is, the main valve

10 moves to the right until the aperture 43 thereof is again aligned with the land 50 of the pilot valve 21, whereupon the land 50 again interrupts the admission of fluid under pressure to the pressure chamber 19 and prevents further movement of the main valve 10 to the right. In this manner for each movement of the pilot valve 21 to the right, as governed by the operation of the solenoids 24 and 25, the main valve 10 follows in response to fluid pressure established in the pressure chamber 19 until the main valve 10 has moved the same distance to the right and the aperture 43 of the main valve 10 is aligned with the land 50 of the pilot valve 21. Moreover, since the distance through which the main valve 10 is moved to the right determines the area of the apertures 32 uncovered, the rate of fluid flow from the passageway 4 to the passageway 5 is therefore controlled proportionally to the relative energization of the solenoids 24 and 25.

In the same manner, when the pilot valve 21 is moved a predetermined distance to the left, fluid under pressure is passed through the aperture 43 of the main valve 10, the annular groove 45 of the pilot valve 21, and the annular groove 47 and associated apertures 49 of the main valve 10 to the pressure chamber 20. Fluid pressure thereby established in the pressure chamber 20 acts upon an annular face 52 of the main valve 10 to move the main valve 10 a corresponding distance to the left, thereby admitting fluid under pressure to the working passageway 6 from the inlet passageway 4 and controlling the flow thereof proportionally to the relative energization of the solenoids 24 and 25. Thus, the movement of the main valve 10 to pass fluid under pressure from the passageway 4 to a selected one of the passageways 5 and 6 is controlled proportionally to the movement of the pilot valve 21 by the solenoids 24 and 25.

To better understand the remaining operations and structure of the two-stage valve 1, I have shown a cross-sectional view of a fluid motor 53 comprising a housing 54 having a cylindrically shaped interior 55, a piston 56 slidably positioned in the interior of the housing 54, and a piston rod 57 rigidly connected to the piston 56 and slidably positioned in an aperture 58 in an end 59 of the motor housing 54. The piston 56 divides the fluid motor 53 into two chambers 60 and 61.

To operate the fluid motor 53 from the control valve 1 the working passageways 5 and 6 are connected respectively to the chambers 60 and 61 of the fluid motor 53 by a pair of tubes 62 and 63, or by other suitable means. Considering the operation of the valve 1 in connection with the fluid motor 53, it will be noted that when the main valve 10 of the control valve 1 is moved to the right, fluid under pressure is passed through the working passageway 5 of the valve 1 to the pressure chamber 60 of the fluid motor 53 forcing the piston 56 thereof to the right providing fluid is not locked in the chamber 61. To provide for the exhaust of fluid from the chamber 61 to permit movement of the piston 56 to the right, a plurality of spaced apertures 64 and an annular groove 65 are formed in the valve sleeve 8. The apertures 64 and groove 65 provide communication between the dump passageway 3 of the housing 2 and the annular groove 34 of the main valve 10 when the main valve is moved to the right. Thus, when the main valve 10 is moved to the right, communication is established between the chamber 61 of the fluid motor 53 and the dump passageway

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3 of the valve 1 through annular groove 36 of the housing 2, annular groove 38 and apertures 40 of the valve sleeve 8, annular groove 34 of the main valve 10, and apertures 64 and annular groove 65 of the valve sleeve 8.

When the main valve 10 is moved to the left, fluid under pressure is passed from the passageway 4 through the working passageway 6 to the chamber 61 of the fluid motor 53 causing the piston 56 to move to the left providing the fluid is not locked in chamber 60 of the fluid motor 53. To provide for the exhaust of fluid from the chamber 60 when the main valve 10 is moved to the left, a plurality of spaced apertures 66 and an annular groove 67 are provided in the valve sleeve 8, the apertures 66 and annular groove 67 being aligned with the dump passageway 3. Thus, when the main valve 10 is moved to the left, communication is established between the chamber 60 of the fluid motor 53 and the dump passageway 3 through tube 62, passageway 5, annular groove 35 of the housing 2, annular groove 37 and apertures 39 of the valve sleeve 8, annular groove 33 of the main valve 10, and apertures 66 and annular groove 67 of the housing 2.

A consideration of the structure of main valve 1 as thus far described will indicate that when fluid under pressure is admitted to the pressure chamber 19 of the valve 1 to move the main valve 10 to the right, such movement is prevented unless fluid stored in the pressure chamber 20 on a previous operation of the main valve 10 to the left is exhausted. Therefore, to exhaust fluid from the pressure chamber 20 of the control valve 1 on movement of the main valve 10 to the right, I provide a plurality of spaced apertures 68 and an annular groove 69 positioned in the main valve 10. Communication is thereby provided between the pressure chamber 20 and the dump passageway 3 through the apertures 49 and annular groove 47 of the main valve 10, the annular groove 45 of the pilot valve 21, the apertures 68 and annular groove 69 of the main valve 10, and the apertures 64 and annular groove 65 of the valve sleeve 8 when the main valve 10 is moved to the right.

In addition, a plurality of spaced apertures 70 and an annular groove 71 are formed in the main valve 10 to exhaust fluid under pressure from the pressure chamber 19 of the control valve 1 to the dump passageway 3 through the apertures 48 and annular groove 46 of the main valve 10, the annular groove 44 of the pilot valve 21, the apertures 70 and annular groove 71 of the main valve 10, and the apertures 66 and annular groove 67 of the valve sleeve 8 when the main valve 10 is moved to the left.

Those skilled in the art will understand that to avoid an unstable condition in the operation of a proportional hydraulic valve, such as control valve 1, the ratio of reactive forces to actuating forces therein must be minimized. For example, I have defined the opposing annular vertical surfaces of the grooves 33 and 34 of the main valve 10 by the numbers 72 and 73. Those skilled in the art will understand that when fluid under pressure is passed from the apertures 32 across the surface 72 to the annular groove 33, for example, the flow of fluid across the surface 72 results, in accordance with Bernoulli's law, in a smaller pressure on the surface 72 as compared with the fluid pressure on the surface 73. That is, a reactive force resulting from the difference in pressures on the surfaces 72 and 73 and dependent upon the rate of

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flow of fluid through the valve 1 is established on the main valve 10. If the reactive force is sufficiently small as compared to the actuating force necessary to move the main valve 10, no difficulty is encountered. Therefore, the ratio of reactive to actuating force must be maintained at a predetermined minimum.

The ratio of reactive to actuating forces may be reduced by reducing the reactive force or by increasing the actuating force. However, the reactive force developed in the main valve 10 is dependent upon the area of the annular surfaces 72 and 73 of the grooves 33 and 34. Moreover, the area of surfaces 72 cannot be reduced beyond a predetermined minimum depending upon the capacity of the valve. That is, to lessen the area of surfaces 72 by reducing the depth of the annular grooves 33 and 34 reduces the capacity of the valve 10 and therefore is not desirable if the capacity of the valve 10 is to be maintained. Moreover, to reduce the area of surfaces 72 by reducing the diameter of the valve 10 is impossible where the depth of groove required for a given length of groove to maintain the capacity of the valve is greater than the radius of the valve.

Since the reactive force of the main valve 10 is controlled by the area of the surfaces 72 is not susceptible to further reduction, it is necessary therefore to increase the actuating force to maintain a desired ratio of reactive force to actuating force. The actuating force could be increased by increasing the size of the solenoids 24 and 25 and arranging the solenoids to engage and directly operate the main valve 10. However, to increase the size of the solenoids is undesirable for reasons of cost and structural limitations. Moreover, by use of the pilot valve 21 in conjunction with the pressure chambers 19 and 20, sufficient pressure is obtained on the relatively large surfaces 51 and 52 to maintain the desired ratio of reactive to actuating force.

The application of the pilot valve 21 introduces a second reactive force in the valve 1. That is, the grooves 44 and 45 of the pilot valve 21 form opposing annular vertical surfaces which I have numbered 74 and 75. Thus, fluid under pressure admitted to groove 44, for example, by moving pilot valve 21 to the right, passes over the surface 74 to produce a smaller pressure thereon than is applied to the surface 75. However, the areas of surfaces 74 and 75 are considerably smaller than the areas of surfaces 72 and 73 because of the relatively small diameter of the pilot valve 21 as compared to the diameter of the main valve 10 and because the cross-sectional areas required of grooves 44 and 45 are less than the cross-sectional areas required of grooves 33 and 34. That is, groove 33 requires a cross-sectional area sufficient to pass a flow of fluid determined by the capacity of the valve 1, whereas the groove 44 requires a cross-sectional area sufficient only to pass a relatively small quantity of fluid required to pressurize the small chambers 19 and 20. Therefore, since the area of surface 74 is considerably smaller than the area of surface 72, a relatively smaller reactive force is developed in the pilot valve 21 as compared to the reactive force developed in the main valve 10 and proportionately small actuating pressure is required of the solenoids 24 and 25 to maintain a desired ratio of reactive force to actuating force necessary for stable operation of the pilot valve 21.

Therefore, in accordance with my invention, I have provided a two-stage proportional hy-

draulic control valve in which reactive forces are reduced by the addition of a pilot valve to permit operation of the control valve by a minimum actuating force thereby reducing the cost of the actuating means of the valve while maintaining stable operating conditions therein.

Further, by my invention I have produced a two-stage proportional hydraulic control valve of simple structure and reliable operation in which proportional operation between the pilot valve and main valve therein is obtained directly by locating the pilot valve within the main valve and by providing suitable cooperatively arranged apertures and annular grooves as described above in detail whereby the use of additional position indicating devices such as springs, linkages, or electrical pickoffs required in conventional two-stage proportional hydraulic valves are eliminated.

While I have shown and described a particular embodiment of my invention, it will be obvious to those skilled in the art that various changes and modifications may be made without departing from my invention in its broader aspects, and I therefore aim in the appended claims to cover all such changes and modifications as fall within the true spirit and scope of my invention.

What I claim as new and desire to secure by Letters Patent of the United States is:

1. A two-stage hydraulic control valve comprising a housing having an inlet passageway, a pair of spaced working passageways, and a hollow cylindrical interior, a cylindrical valve sleeve assembled in fixed position in said housing interior, said valve sleeve having a cylindrical hollow interior, a cylindrical main valve in said valve sleeve having a hollow cylindrical interior and opposite projecting ends of reduced diameter, said main valve having an external diameter slightly less than the interior diameter of said valve sleeve so as to be slidably positioned in said valve sleeve, opposite closed ends for said housing, said ends having aligned apertures to accommodate said projecting ends of said main valve and provide for slidable movement of said main valve in said valve sleeve, said valve sleeve, said housing ends and said main valve having adjacent surfaces forming a pair of pressure chambers, one at each end of said main valve, a cylindrical pilot valve in said main valve having an external diameter slightly less than the interior diameter of said main valve so as to be slidably journaled in said main valve, said housing, valve sleeve, and main valve having a plurality of associated spaced apertures and annular grooves to provide for the passage of fluid from said inlet passageway to a selected one of said working passageways dependent upon the position of said main valve in said housing, said valve sleeve and said housing having a plurality of apertures and annular grooves spaced to provide for the removal of fluid from a selected one of said working passageways dependent upon the position of said main valve in said valve sleeve, said main valve, said pilot valve and said sleeve having a plurality of apertures and annular grooves cooperatively spaced to provide for the removal of fluid from a selected one of said pressure chambers dependent upon the operation of said main valve, said valve sleeve, said main valve and said pilot valve having a plurality of cooperatively spaced apertures and annular grooves to admit fluid under pressure to a selected one of said pressure chambers dependent

upon the operation of said pilot valve to actuate said main valve in a desired direction, and actuating means external of said housing and engaging said ends of said pilot valve to operate the same.

2. A two-stage hydraulic control valve comprising a housing having a hollow cylindrical interior, a spaced inlet passageway, a pair of spaced working passageways, and a dump passageway, each of said passageways communicating with the exterior of said housing, a valve sleeve having a cylindrical periphery engaging the interior of said housing and having a hollow cylindrical interior, a main valve slidably positioned in said valve sleeve, said main valve having an outer periphery engaging the interior surface of said valve sleeve, a hollow cylindrical interior of relatively small diameter as compared to the diameter of its outer periphery, and opposite ends of reduced diameter, opposite closed ends for said housing, said housing ends having aligned apertures to accommodate the ends of said main valve, a cylindrical pilot valve slidably journaled in the interior of said main valve, said housing ends, said valve sleeve and said main valve having adjacent surfaces forming two pressure chambers one at each end of said main valve to control the slidable movement thereof in accordance with the relative fluid pressures in said pressure chambers, said valve sleeve, said main valve, and said pilot valve having a plurality of associated spaced apertures and annular grooves to admit fluid under pressure to a selected one of said pressure chambers in response to movement of said pilot valve in a selected direction thereby to control the operation of said main valve in response to a selected operation of said pilot valve, said valve sleeve and said main valve having associated spaced apertures and annular grooves to admit fluid under pressure to a selected one of said working passageways in response to the selected movement of said main valve by said pilot valve, said valve sleeve and said main valve having a plurality of associated spaced apertures and annular grooves to pass fluid from a selected one of said working passageways to said dump passageway in response to a selected operation of said main valve, said main valve, said pilot valve and said valve sleeve having a plurality of associated spaced apertures and annular grooves to allow fluid to be exhausted to said dump passageway from the particular one of said pressure chambers in whose direction said main valve is moving on a particular operation thereof to avoid the development of a back pressure on said main valve preventing operation thereof, and actuating means external of said housing and engaging opposite ends of said pilot valve to operate the same.

3. A two-stage hydraulic control valve comprising a housing having an elongated cylindrical interior, a spaced inlet passageway, a pair of spaced working passageways, and a dump passageway, each of said passageways communicating with the exterior of said housing, a valve sleeve having a cylindrical periphery engaging the interior of said housing and a hollow cylindrical interior, a main valve slidably positioned in said valve sleeve, said main valve having an outer periphery engaging the interior surface of said valve sleeve, a hollow cylindrical interior of relatively small diameter as compared to the diameter of its outer periphery and opposite ends of reduced diameter, opposite closed ends for said housing, said housing ends having aligned apertures to accommodate the ends of said main valve, a cylindrical

pilot valve slidably journaled in the interior of said main valve, said housing, valve sleeve, and main valve having a plurality of spaced apertures and a plurality of associated annular grooves cooperatively spaced to provide communication between said inlet passageway and a selected one of said working passageways dependent upon the position of said main valve in said valve sleeve, said valve sleeve having an additional plurality of apertures and annular grooves cooperatively spaced with respect to said first mentioned apertures and annular grooves to exhaust fluid under pressure from a selected one of said working passageways in response to a selected operation of said main valve, a pair of pressure chambers, one at each end of said valve formed by adjacent surfaces of said valve sleeve, said housing ends and said main valve, a pilot valve slidably positioned in said main valve, said pilot valve having a pair of spaced annular grooves forming a centrally disposed land portion, said main valve having an additional plurality of spaced apertures and annular grooves cooperatively arranged with respect to said land portion and said spaced annular grooves of said pilot valve to admit fluid under pressure from said inlet passageway to a selected one of said pressure chambers to selectively oper-

ate said main valve in response to a selected operation of said pilot valve and to interrupt communication between said inlet passageway and said pressure chambers when said main valve and pilot valve are aligned, said main valve having a further plurality of spaced apertures and annular grooves cooperatively arranged with respect to said apertures and annular grooves of said valve sleeve to exhaust fluid under pressure from a selected one of said pressure chambers dependent upon the operation of said main valve, and actuating means external of said housing and engaging said ends of said pilot valve to operate the same.

EARLE R. WALTHERS.

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